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Space Transportation Technology Workshop or Section Title:

Electromagnetic Propulsion

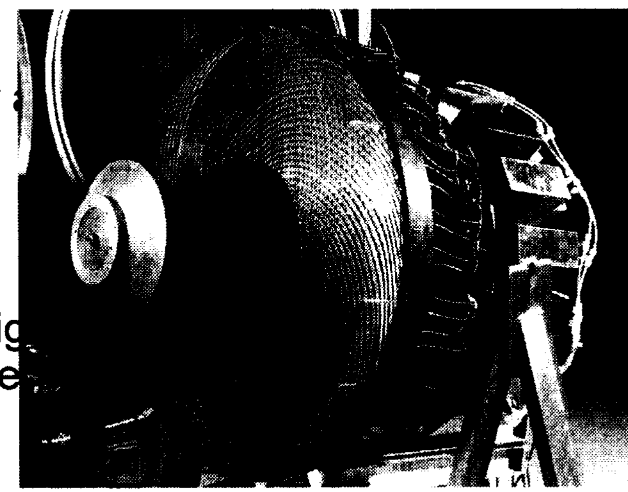
- Overview

  Specific Electromagnetic Propulsion Topics

  - Technology for Pulse Inductive Thruster
  - Flight Weight Magnet Survey
  - Magnetic Flux Compression

- Summary

- **Technology goals and objectives**
  - **Revisit PIT technology and design, build, and test a multi-repetition rate pulsed inductive thruster.**
  - **Solid-State Switch Technology**
    - High repetition rate and extreme long lifetime
    - High peak currents and high/rapid initial current rise time
  - **Pulse Driver Network and Architecture**
    - Recovery of reflected energy
    - Pulse shape control for optimum pulse waveform
- **Background**
  - **Research history since 70's at TRW**
  - **Characterized by μ-second, MW-power pulsed operation providing high thrust efficiency over a wide range of specific impulse.**
  - **Single-shot spark gap operation**
    - Severe lifetime limitations
    - Multi-rep rate operation severely limited
    - Require gaseous working medium to enable hig
    - Require extreme simultaneous discharge trigge operation



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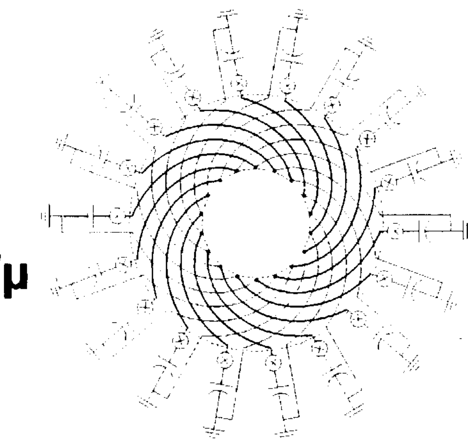
Electromagnetic Propulsion (PIT)

- **Current status**
  - **PIT Performance Characteristics**
    - Spec. Impulse: 2,000-8,000 s
    - Efficiency: 20-50%
    - Single shot operation using spark gaps
      - Initial Rise Time in one switch: **dI/dt=30kA/µ**
      - Peak Current: **15kA**
  - **Solid-State Switch Technology**
    - SCR: 5 kV, 4.6 kA, dI/dt=20 kA/µs
    - IGBT: 15 kV, 3kA, 10's of kHz
- **Major accomplishments**
  - **Designed two test circuits to conduct testing of key parameters**
  - **Procured test equipment and circuit components**
  - **Identified manufacturers to supply high-power solid-state switch technology**
- **Near term plans**
  - **Test and evaluate candidate switch components**



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FLIGHT WEIGHT MAGNETICS

MAJOR RESEARCH GOALS:

- **Determine/develop light weight high performance magnetic materials. for potential application Advanced Space Flight Systems as these systems develop.**

MAJOR ACCOMPLISHMENTS:

- **Literature searches resulted in selection of Ultra Pure Aluminum to fabricate an electromagnet to generate a pulsed magnetic field in a cryogenic temperature environment . This selection was based on density, temperature-dependant and residual resistivity, as well as magneto-resistance characteristics.**
- **Acquired magnetic pressure equations (stress analysis).**
- **Located experienced source for electromagnet fabrication and testing**

STATUS:

- **A grant is currently in place with Louisiana State University (LSU) to construct a 99.999% Purity Aluminum solenoid. Will be delivered to MSFC after fabrication and testing is completed.**

FLIGHT WEIGHT MAGNETICS

MILESTONES:

November 2000

- **Solenoid to be completed by LSU.**
- **Testing at the National High Magnetic Field Laboratory (NHMFL) in Tallahassee, FL. which includes:**
  - **Magneto-resistance recorded while exposed to externally applied steady state magnetic fields up to 20 Tesla and temperatures ranging from 4 to 300 Kelvin.**

December 2000

- **Testing at the NHMFL in Los Alamos, NM. which includes:**
- **Pulsed excitation to field maximum of 2 Tesla.**
- **Solenoid and cryogenic system temperature recorded during excitation.**
- **Measurements of the total solenoid resistance, inductance, and stress/stain before, during, after each excitation.**

January 2001

- **Solenoid and all data delivered to MSFC.**

Electromagnetic Propulsion – Magnetic Flux Compression Reactors

Goals …

Enable rapid/robust/reliable omni-planetary space transportation within realistic development and operational costs constraints

Objectives …

10× improvement propulsion capability
- high thrust-to-weight ratio
- high specific impulse
- high Δv maneuvering

Abundant spacecraft electrical power
- deep space capability (non-solar)
- high capacity (multi-MW)
- high specific power (> 10 kW/kg)

Technical Challenges …

Demonstrate the feasibility of pulsed magnetic flux compression reactor concepts using detonation plasma

Research and develop flightweight pulsed magnet technologies based on ultra conductors and superconductors

Fundamental plasmadynamics research
- electrical conductivity / R_m
- interactions with magnetic field
- plasma instabilities
- magnetic flux diffusion
- plasma turnaround

Fundamental magnetics research
- high purity aluminum windings
- type I / type II SC windings
- HTSC flux compression surfaces
- lightweight structure issues
- pulsed operation issues

Approach …

Develop and test a moderate scale (1/2-m) prototype flux compression reactor using non-nuclear plasma detonation source

Rationale

Plasma micro-detonation flux compression reactors …

- amenable to propulsion & electrical power reactor concepts
  - high jet power / multi-megajoule energy bursts
  - inductive energy storage / pulse power for ignition driver
  - production of spacecraft bus power
- compatible with advanced target concepts
  - inertial confinement fusion (ICF)
  - magnetized target fusion (MTF)
  - high energy density chemical detonations
- low-weight / compact / low-cost

… capable of satisfying omni-planetary exploration goals

Magnetic Flux Compression Reactor Principles

Energy Conversion Processes

chemical/nuclear → kinetic → electrical → kinetic

Principle of Operation

- detonation charge transformed into kinetic energy of moving conductor
- magnetic seed field is trapped and compressed by moving conductor
- kinetic energy is temporarily stored in rapidly compressed magnetic field
- electrical power can be extracted inductively through loaded circuit
- compressed field energy reverses conductor motion and returns kinetic energy

Global Energy Conservation

> 80%

conversion efficiency

Major Research Tasks

- Modeling of reactor performance
  - first order performance analyses
  - MHD code development
  - finite element model of coupled circuits

- Investigation of pulsed magnetic fields on HTSC materials
  - laboratory measurements of magnetic diffusion properties
  - validation of magnetic diffusion model

- Basic plasma physics experiments
  - fundamental flux compression experiment
  - inductive measurement of plasma jet electrical conductivity
  - plasma jet collisional processes
  - validation of MHD codes
  - Rayleigh-Taylor instability (revisited)

- Flightweight pulsed magnet technology
  - high purity aluminum winding magnet
  - superconductor winding magnet

Key Summary Points

- magnetic flux compression suitable for spacecraft propulsion & power
  - enables omniplanetary exploration
  - multimegawatt energy bursts
  - terawatt power bursts
  - pulse power for low impedance dense plasma devices
  - direct thrust production
- innovative design strategy
  - detonation plasma armature
  - type-II superconductor stator
  - intermittent firing capability
- constrains weight and size of overall system
- inductive storage pulse power source
- near-term ($\approx$18 month) scientific feasibility program
- concept based on feasible extrapolations of current technology